TACTICAL SATELLITE 3
THE 4S SYMPOSIUM

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ABSTRACT

Tactical Satellite 3 is an Air Force Research Laboratory Science and Technology (S&T) initiative that explores the capability and technological maturity of small, low-cost satellites. It features a low cost "plug and play" modular bus and low cost militarily significant payloads - a Raytheon developed Hyperspectral imager and secondary payload data exfiltration provided by the Office of Naval Research. In addition to providing for ongoing innovation and demonstration in this important technology area, these S&T efforts also help mitigate technology risk and establish a potential concept of operations for future acquisitions.

The key objectives are rapid launch and on-orbit checkout, theater commanding, and near-real time theater data integration. It will also feature a rapid development of the space vehicle and integrated payload and spacecraft bus by using components and processes developed by the satellite modular bus initiative. Planned for a late summer 2008 launch, the TacSat-3 spacecraft will collect and process images and then downlink processed data using a Common Data Link. An in-theater tactical ground station will have the capability to uplink tasking to spacecraft and will receive full data image. An international program, the United Kingdom Defence Science and Technology Laboratory (DSTL) and Australian Defence Science and Technology Organisation (DSTO) plan to participate in TacSat-3 experiments.

1. INTRODUCTION

In future conflicts, military space forces will likely face challenges ranging from defending against opposing systems to dealing with rapidly changing technology and support needs. The Air Force describes its vision for responding to these challenges as operationally responsive space (ORS). [1] TacSat-3 ooriginated in 2004 as part of the initiative addressing the military's need for responsive, flexible, and affordable systems operating in the space, TacSat-3 serves as the first in the series of small satellites to go through a formal payload selection process based on the combatant commands' recommendations and a review by a flag officer panel. [2] TacSat-3's mission was selected for specific capabilities to meet user needs, and to demonstrate those capabilities within cost and schedule constraints. TacSat-3 will experiment with a Hyperspectral Imaging (HSI) capability direct to the tactical warfighter within 10 minutes of a collection opportunity. The small satellite consists of three distinct payloads: the Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS) hyperspectral imager (HSI), the Office of Naval Research Satellite Communications Package (SCP), and the Space Avionics Experiment (SAE).

TacSat-3 will demonstrate evolutionary steps and traceability towards objective system goals for the capabilities and processes including rapid response to a user defined need for material detection and identification, and battle damage assessment. Additionally, it will demonstrate traceability to enable launch processing at the launch base faster than seven days. Finally, it will feature a rapid development of the space vehicle and integrated payload and spacecraft bus by using components and processes developed by the Operationally Responsive Space Modular Bus program. The TacSat-3 CONOPS breaks old paradigms and gives theater commanders the first realistic opportunity for responsive, dedicated space capabilities at the operational and tactical level.

Serving as the mission's primary experiment, the ARTEMIS HSI, developed by Raytheon Company, will rapidly supply data on target detection and identification, as well as

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15. SUBJECT TERMS

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information related to preparing the battlefield and assessing combat damage. The SCP is the secondary payload and will collect data from sea-based buoys and transmit the information back to a ground station for expeditious communication to the Warfighter. The third payload, the AFRL-designed SAE, will validate plug-and-play avionics capability, which will involve the use of reprogrammable components to integrate the SAE experiment and the spacecraft structure. Planned as a one year S&T mission for launch in early fall 2008, the Tactical Satellite-3 (TacSat-3) spacecraft features an onboard processor, which will provide real-time data (within 10 minutes of its collection) to the combatant commander in the theater of interest. The small TacSat-3 satellite, weighing less than 400 kilograms (880 pounds), will also exhibit a first generation modular bus providing the adaptability for future TacSat missions.

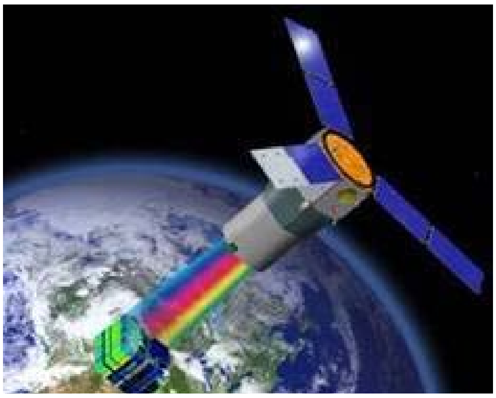

Figure 1. TacSat-3 Concept

The TacSat-3 program is a team effort and mission partners include the Army Space and Missile Defense Command, Air Force Space Command, the Department of Defense's (DOD) Operationally Responsive Space Office, the Office of Naval Research (ONR), the National Air and Space Intelligence Center (NASIC), the National Geospatial-Intelligence Agency (NGA), and the Air Force Research Laboratory's Sensors Directorate. As a key team member in the TacSat-3 project, the Space and Missile Systems Center's Space Development and Test Wing (SDTW), located at Kirtland AFB, NM, is providing the Orbital Sciences Corporation's Minotaur 1 launch vehicle. The four-stage rocket consists of two stages taken from retired Minuteman intercontinental ballistic missiles, and another two stages from Orbital's Pegasus booster. TacSat-3 mission operations will accomplished in the SDTW's Mission Operations Center at Kirtland AFB.

2. SYSTEMS ENGINEERING

Systems engineering tools and practices are being used extensively in TacSat-3's development. These tools and practices include, but are not limited to: requirements definition, allocation and verification, use of systems engineering management tools such as risk management, interface control, configuration control, design reviews and analyses. These tools were modified to meet the needs of a small class spacecraft, and novel approaches to documentation and implementation minimized developmental costs while maintaining an appropriate level of mission assurance. [3]

The TacSat-3 program is somewhat unique in that there is no prime contractor and AFRL serves as the program integrator. As a result, AFRL is solely responsible for the requirements of the system as well as defining the experimental design. Due to the small size of the team, the engineering team provides a critical link between the high level requirements and structuring of the detailed design requirements for subsystem development. The success of this effort to date can be directly attributed to the quality and technical expertise of the government systems engineering team as well as the contractor systems engineering team. A large portion of the team derives considerable lessons learned from previous missions especially the ill-fated Warfighter-1 as well as Tactical Satellite 2. These experiences allow the 'organic' incorporation of lessons learned.

The primary contractual elements of the TacSat-3 system are ARTEMIS, the Sensor Processor, the Spacecraft Bus (aggregate of power, command and data handling, power control, thermal control, guidance, navigation and control, and structures), the Common Data Link system, the two secondary payloads (SAE and SCP), and the Assembly, Integration and Test (AI&T) effort. Each of these elements are handled by different companies contracted to AFRL. These individual contractors came with their own strengths and weaknesses as well as their own management and engineering cultures. A large effort was expended initially to calibrate these entities to the needs of the TacSat-3 program as well as developing a working relationship between them and the government.

As the government systems engineering team is significantly geographically separated as well as separated with all contractor elements; communications between these elements became an essential element to the team's effectiveness. Electronic file sharing capabilities are essential to the ability to derive consensus on requirements, share these requirements, review design data, share and review test plans, review and share test data, etc. A web based 'Extranet' was used. And in the case of the ARTEMIS sensor the government systems engineering team had direct access to design data. This access was invaluable in the identification and mitigation of risks and issues. A significant effort is expended to ensure the government systems engineering team had insight into the contractor's electronically produced data as it is developed and tested by the subsystem provider. Overall, the ability to share key technical data quickly allows for timely technical decisions reducing impacts to both cost and schedule. The added insight also reduces the overall risk for the system development

2.1 Risk management

As communication between government (prime integrator) and the individual contractor became easier and increased; a common understanding of risk management was developed. Each contracted element was required to brief their risks and mitigation strategies at each formal and informal review. For more complex pieces of the system, risks were discussed weekly in status teleconferences. Essential elements of these discussions were gaining understanding of the risk tolerance, and how risks propagated throughout the system. As these risk data were gathered by the government systems engineering team, these were pulled into a common TacSat-3 risk matrix.

Each identified risk is assigned a likelihood or probability of occurrence and a severity or consequence of the risk occurring. Assessments for likelihood and severity were given a category corresponding to level of risk. Table 1 shows the risk management assessment process used by TacSat-3. Rarely risks were easily categorized into a quantitative probability of occurrence per mission. A large amount of funds can be spent to determine the exact probability of occurrence for the risk. TacSat-3 mostly assessed likelihood ratings based on the qualitative assessments of remote, unlikely, moderately likely, likely and very likely. Having the quantitative levels available guided the assessment of likelihood for a particular risk. In only one instance was an attempt made to perform a quantitative determination of a risk's probability of impacting the mission.

Likelihood Rating			
Color	Category	Qualitative Assessment	Quantitative Probability Per mission
Green	A	Remote/ Very Unlikely	p ~ 1/1000
Green	B	Unlikely	p ~ 1/100
Yellow	C	Moderately Likely	p ~ 1/10
Red	D	Likely	p – 1/3
Red	E	Very Likely/ Near Certainty	p – 2/3

Severity			
Category	Qualitative Assessment	Quantitative Performance Impact	Quantitative Cost Impact
1	Minor	< 1%	< $100k
2	Moderate	– 1-5%	$100k-$200k
3	Medium	5-15%	$200k-$500k
4	Serious	15-50%	$500k-$1M
5	Critical	>50%	>$1M

Table 1. Risk Management Assessment

The quantitative assessment performed was in response to an unknown electronics parts susceptibility to radiation caused single event effects with special emphasis on destructive effects. As the TacSat-3 system is in many places a single-string system (many single points of failure); a weak component could cause mission failure. The severity of these risks were determined to be critical or category 5. With this level of consequence, special attention was made to parts with unknown likelihood of failure. Testing of individual components was accomplished if no data were available via either analysis or other information sources.

Risks are assessed from a technical impact as well as a cost and schedule impact. This allowed the TacSat-3 program management to intimately understand the linkages between technical risks and their impact on cost and schedule. As mitigation efforts often involved additional resources such as cost and schedule, trades could

be performed to determine if the proverbial cure was worse than the consequences of the risk. At other times, system design trades could be made to keep a level of performance while mitigating effects to cost and schedule.

3. TECHNICAL DESCRIPTION

3.1 Primary Payload

HSI provides unique benefits to the warfighter. The spectral information in each image lends itself to anomaly detection in a given scene, spectral matching of elements within the scene, and ultimately capabilities to distinguish man-made materials from natural materials. [4] The raw data (often referred to as a data cube) has not only two spatial dimensions, but a spectral dimension as well. Raytheon Space and Airborne Systems with collaboration on the imaging spectrometer from NASA's Jet Propulsion Laboratory (JPL) designed and fabricated the Advanced Responsive Tactically-Effective Military Imaging Spectrometer (ARTEMIS). The goals of responsive space motivated all aspects of the ARTEMIS sensor payload development. Design trades were carefully evaluated at each step with cost and schedule impacts of foremost consideration. The resulting sensor maintains technical performance while containing costs under a rapid development schedule (delivered 15 months after contract award). ARTEMIS makes extensive use of commercial off-the-shelf components and industry standard interfaces to create an affordable, high-performance space-based surveillance option. It also realizes the operationally responsive space vision of fast, flexible launch and use capability. [5]

ARTEMIS was envisioned to comprise a high resolution pushbroom spectrometer with a single focal plane array (FPA) that is sensitive over the visible to shortwave infrared spectral range. This was done to maximize optical quality and minimize design complexity, Foremost considerations were optical quality and simplicity. Fortunately significant progress has been made in hardware development and in overall optical design for imaging spectrometers. Airborne imaging spectrometers such as the Army COMPASS sensor utilize single focal plane arrays with high quantum efficiency across the solar reflective spectral region with the end result being a simplified imaging spectrometer design without multiple focal planes and the resulting alignment challenges. A significant military requirement for geolocation accuracy across the full spectrum of each spatial pixel is Spectral co-alignment. Electron beam lithography techniques developed at the Jet Propulsion Laboratory (JPL) enable the production of optically efficient gratings on curved substrates. These advanced gratings are required to realize the full potential of the Offner form. JPL has made significant progress in optical designs that have highly uniform spectral and spatial response functions. This uniformity is crucial for the calibration and subsequent exploitation of imaging spectrometer data. An inexpensive yet high quality sensor is made possible by the maturation of hardware and design. Figure 2 shows an artist's conception of the AREMTIS payload

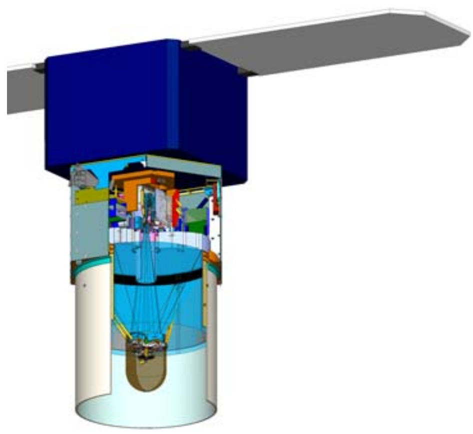

Figure 2. Raytheon ARTEMIS HSI Payload

The telescope, based on an AFRL straw man design, was chosen to optimize the performance of the imaging spectrometer. This design choice affected the performance of the high resolution imager (HRI) by limiting the image quality but is consistent with the responsive space goal of performance sufficiency. The telescope is a standard Ritchey-Chrétien form and the secondary mirror has a built-in focus mechanism for on-orbit optimization. The imaging spectrometer is of the basic Offner form consisting of two powered reflecting surfaces comprising the primary and tertiary elements. The secondary mirror is replaced by a curved grating for dispersion and is the limiting stop of the system. This form has the merit of being simple, compact, and both spatially and

spectrally uniform. Spatial and spectral uniformity is critical to the operational performance of imaging spectrometers as it enables robust exploitation of data products. A dual-angle blaze grating was selected largely due to its superior performance in reducing the effect of obscurations at the grating stop. The grating was also designed to optimize the signal-to-noise ratio (SNR). The goal is to make the SNR performance approximately equal at all wavelengths. The imaging spectrometer design also relies upon a substrate-removed MCT focal plane array that extends its sensitivity into the blue wavelengths to cover the full spectral range. This single focal plane eliminates the co-registration issues associated with multi-FPA systems. The quantum efficiency of the FPA is better than 70% at all wavelengths and the array is equipped with a three-zone blocking filter for order sorting.

The payload features an on-board health monitor (OBHM to establish and monitor on-orbit functionality and to evaluate spectral calibration performance). The OBHM consists of a small blackbody source with a color temperature of about 2200 K, an elliptical reflector, and a spectral filter. The OBHM source is placed at the center of the telescope secondary mirror and is within the shadow of the obscuration. The OBHM is not intended to be a radiometric source as its irradiance will vary on orbit and is not verifiable. It will be quite useful for confirming spectral calibration via the spectral filter. The OBHM does not completely fill the imaging spectrometer limiting the illumination of the grating to the center. Performance is improved by the grating design trade result, as a multi-zone grating would not be as efficient at all wavelengths as is a dual-angle blaze grating.

The radiometric performance of the ARTEMIS sensor has been modeled in detail. The model is highly flexible, is designed to permit the rapid evaluation of the impact of sensor design decisions, and is based upon robust sensor modeling theory. It predicts signal levels, individual noise sources, the signal to noise ratio (SNR), the noise equivalent spectral radiance (NESR), and saturation radiance. This model has been used extensively throughout sensor development. The model requires at-aperture spectral radiance, system etendue, the sampling interval, knowledge of the optical efficiency of each optical element as a function of wavelength, the spectral quantum efficiency and well depth of the FPA, the electronic conversion properties and noise terms associated with the FPA, the analog to digital conversion bits, the temperature of the spectrometer to calculate the background noise contribution, and the integration time for a particular measurement. The ARTEMIS atmosphere was selected to be more representative of average viewing conditions and surface reflectances. Models were also generated to model saturation and minimum illumination conditions.

The ARTEMIS sensor demonstrates the capability of producing a high quality spectral imaging system within an aggressive schedule and a constrained budget. This is a credible first step toward the transition to the responsive space paradigm with inexpensive but capable payloads ready for rapid integration onto plug and play satellite buses. The ARTEMIS design fully exploits the technological advancements accomplished during the previous decade in the areas of focal plane arrays, gratings, and imaging spectrometer design.

3.2 Sensor Processor

An innovative aspect to controlling cost and schedule was the separation of the processing capabilities from the sensor itself. These functions are performed by the ARTEMIS Sensor Processor (SP). Control of the functions on the sensor, power switching, collecting state of health data from ARTEMIS, and storing ARTEMIS data are prime functions of the SP. Additionally, a fundamental capability of the SP is to autonomously process data cubes from ARTEMIS and produce tactically relevant information for dissemination directly to the fielded warfighter. These products are primarily in the form of text products along with some imagery dependent upon the dissemination method. [5]

The Sensor Processor uniquely separates payload data management such as storage, processing, and control separate from an integrated sensor and processor. This allows for the ARTEMIS and Sensor Processor combination to be hosted on a more generic platform such as a modular bus by adapting only a piece (the SP) as required for future concepts. Additionally, it is easily expandable into a plug and play component by consolidating the sensor electrical, power, and software interfaces into a single unit. This single interface paradigm is essential to the responsive

space. The primary contractors building the sensor process are SEAKR Engineering, Inc. and the Space Computer Corporation (SCC). SEAKR Engineering is responsible for the hardware development, and SCC is responsible for the software development of both the data processing algorithms as well as the software for controlling the ARTEMIS sensor.

3.3 Auxiliary Payloads

The Satellite Communications Package (SCP) is provided by the Office of Naval Research and has two distinct TacSat-3 functions: perform data exfiltration from ocean-based buoys and downlink tactical data products directly to the fielded warfighter. SCP is essentially a UHF radio with internal store and forward capabilities. Downlinking tactical data products via UHF services is in considerably more fielded systems in theater than the CDL, and pushes the data to a lower echelon to be utilized from not only a division level but possibly down to a single unit of action such as a company or brigade. The AFRL designed Satellite Avionics Experiment (SAE) will validate plug-and-play avionics capability, which will involve the use of reprogrammable components to integrate the SAE experiment and the spacecraft structure.

3.4 ORS Modular Bus

Another significant objective of the TacSat-3 was the development of a first generation modular bus. Built by ATK Space (formerly Swales Aerospace), Beltsville, MD, the Responsive Space Modular Bus (RSMB) concept is designed to host multiple payloads for launch on small expendable launch vehicles at very short notice, RSMB provides considerable power, precision pointing, and significant data throughput for sophisticated military and scientific payloads. The RSMB is a zero momentum, 3-axis stabilized, Earth-pointing bus designed to provide a highly stable platform for sophisticated imaging payloads requiring both precision and agility in their ability to target any point on the Earth. Additionally, RSMB can serve as a platform for laboratory technology validation and mission CONOPs development. The program demonstrates modular spacecraft bus standards, interfaces, and processes to meet the goals of the Department of Defense's Operationally Responsive Space (ORS) initiative that seeks rapid, low-cost space assets launched to support the needs of tactical warfighters. This requires that tactically relevant space system performance be delivered much faster and at lower cost. This adaptable, low-cost modular bus enables the tactical warfighter to rapidly deploy tactical satellites as low-cost consumables to fill critical requirements. ATK Space provided the critical design, fabrication and integration of the bus, and is providing support to AFRL for spacecraft integration and test, launch and on orbit operations. The ATK Space design features robust power capability with 900 Watts max and the bus top deck can support 160+ kilogram payloads with an adaptable payload interface to support multiple payload configurations. Figure 3 shows the modular bus during component integration. Flight software is being developed by Interface and Control Systems, Inc. and is tested on the on the ATK "flatsat" prior to delivery to AFRL. ATK Space was awarded the Phase II contract in late May 2006 and delivered the modular bus to less than 15 months later in September 2007.

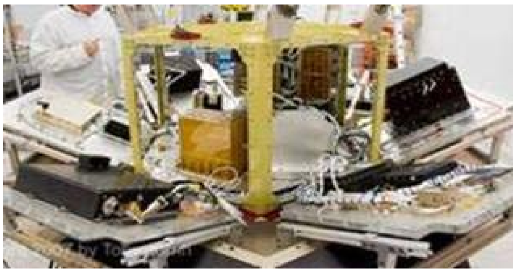

Figure 3. ATK Space Modular bus

The long-term responsive goal of ORS is that modular satellite assembly and test be accomplished in a matter of days for a fraction of the cost of current buses. [6] Space technologies, such as satellites, traditionally have taken years, if not decades, to develop. However, there are many space unique challenges that must be addressed: limited market, long-lead components, varied orbital environments and power profiles, varied payload requirements and interfaces, varied attitude measurement and control requirements, high component costs, high costs for high reliability, etc. Example characteristics desired in the modular bus design are: prudent modularity for rapid customization, standardized interfaces, plug-and-play, internet-like data architecture, robust design to span varied requirements, communications hardware to interface with theater intelligence, surveillance, and reconnaissance (ISR) networks, intelligent adaptation to open standards such as Ethernet,

Spacewire, and USB (to accommodate power delivery, synchronization, and fault tolerance), common software adaptability via scripts and data sheets, rapid assembly and test, and autonomous satellite operations.

To build on-demand satellites to support ORS goals, AFRL researchers have turned in part to the commercial electronics industry for inspiration. There, the plug and play concept--in which components manufactured by different companies are compatible and can integrate autonomously into a single operating system--has been around for more than a decade. The TacSat-3 Spacecraft Avionics Experiment (SAE) Plug-N-Play demonstration will serve as a building block for implementation of plug and play technologies. It will feature a "Smart Deck" with SPA-U host, four SPA-U ports, and a data handling system. It also includes MSI's Intelligent Power and Data Ring with multiple processing nodes, a Spacewire/SPA-S link between Sensor Processor and C&DH for backup downlink capability of HSI data. Additionally, the payload will provide a backup GPS for spacecraft using duplicate Surrey GPS receiver and several SPA-U PnP experiments: a sun sensor and rate sensor and a Smart Deck temperature sensor.

Final assembly, integration, and test of the modular bus and payloads are being accomplished in AFRL's Aerospace Engineering Facility (AEF) with an integrated team of government and contractor engineers and technicians. ATA Aerospace provides in-house

Figure 4. Integration and Test

support to the TacSat-3 team and helps complete the integration of components, performance verification testing, solar array deployment, sensor calibration, RF compatibility testing, and space qualification testing using vibration test facilities and thermal vacuum chambers in the AEF. Figure 4 shows the I&T team during vibration testing in the AEF. Upon completion, the space vehicle will be shipped to the NASA Wallops Island facility for integration with the OSC Minotaur I launch vehicle procured by the Space Development and Test Wing. Launch is currently planned for late summer 2008. Figure 5 shows a Minotaur I rocket at the NASA Wallops Island facility.

Figure 5. Minotaur I Launch Vehicle

3.5 Common Data Link

The enormous data size of the raw data cubes produced by the ARTEMIS sensor requires a large bandwidth downlink which CDL provides. Common Data Link (CDL) is the U.S. military's standard wideband communications waveform for Intelligence Surveillance and Reconnaissance (ISR) in airborne platforms. In supporting this standard, the military has numerous air, sea and ground CDL systems for theater connectivity. A CDL system in space brings tactical ISR data directly into existing theater ground stations, allowing for responsive tasking and collection. This high data rate is essential to providing a routine store and forward concept of operations when the satellite is not performing a tactical mission. CDL was first used in space on TacSat-2 which launched in December of 2006. TacSat 3 takes the CDL communications payload a step further with networking capability and multiple data rates to continue demonstrating direct theater tasking, collection and dissemination. [7]

The Common Data Link communications package provides high speed data downlink and uplink functions. The Common Data Link also allows TacSat-3 to be compatible with existing fielded infrastructure, therefore minimizing unique ground station requirements. The CDL communications package can provide up to 274 Mbps of bandwidth. This high data rate is essential to providing a routine store and forward concept of operations when the satellite is not performing a tactical mission. Additionally, lower data rates are available for potential Remote Operated Video Enhanced Receiver (ROVER) connectivity. Rover is a portable terminal that displays sensor data from multiple airborne platforms across Ku, C, and L-Band with over 1000 units in use. L-3 Communications West designed and manufactured the TacSat-3 CDL communications package. Although TacSat's CDL was space qualified, it is a derivative of an aircraft design and imposes significant mass and power penalties. As follow-on effort, L-3 is working with AFRL and the ORS Office to a space version of the CDL which will dramatically reduce both the size and power requirements.

Figure 6. L3 Comm Rover Terminal

4.0 CONCEPT OF OPERATIONS

Mission operations for TacSat-3 will be conducted in the Space Development and Test Wing's mission operations center where control of the satellite and routine tasking will occur. TacSat-3 experiments will address several military problems. The "stove pipes" associated with many of our current space systems tend to restrict opportunities for horizontal integration and network centric operations. Currently, theater commanders must compete with each other and other government agencies for priority in accessing our limited global space systems. TacSat-3 will demonstrate on-demand; cost-effective augmentation of our space forces which will permit a tailoring of space capabilities for the warfighter in response to specific and emerging crises. TacSat-3's Concept Of Operations **(**CONOPS) can be classified into two different modes: routine and tactical. The routine mode is for collecting HSI data outside of the assigned theater of operation. The tactical mode is reserved for anytime the spacecraft can collect over an assigned theater of operation. The primary purpose of the Tactical Satellite series is to provide the tactical warfighter a dedicated space asset, and as such the tactical mode is the first priority. However, all space systems will have global capabilities due to the nature of orbiting the Earth. Demonstrating the synergy of these two modes is a major goal for TacSat-3.

TacSat-3 follows the TacSat experimental series philosophy of providing COCOMs realistic opportunities for responsive, dedicated space capabilities at the operational and tactical level. The TacSat-3 spacecraft will collect and process images, then downlink material identification (ID) text, geolocation, and/or downlink full data images using the already fielded and established Common Data Link as well as fielded Ultra High Frequency (UHF) units. An in-theater tactical ground station will have the capability to uplink tasking to the spacecraft and will receive full data image. The TacSat-3 hyperspectral imaging (HSI) payload will conduct spectral surveillance fused with high resolution panchromatic (PAN) imaging. Depending on how rapidly TacSat HSI spectral products are generated, the system may be able to cue other sensors or respond to tip-offs or cues from other intelligence and surveillance (ISR) assets.

The sequence starts with the warfighter sending a collection task to the CDL ground station prior to a collection opportunity. A collection is a defined as any time TacSat-3 can collect a hyperspectral image within the opportunity is assigned in theater. Figure 6 shows the sequence of events for the TacSat-3 tactical CONOPS. The CDL ground station uplinks the formatted tasking data to the satellite. The tasking can be modified at any moment until after a short period

of time after acquisition of signal with the CDL ground station.

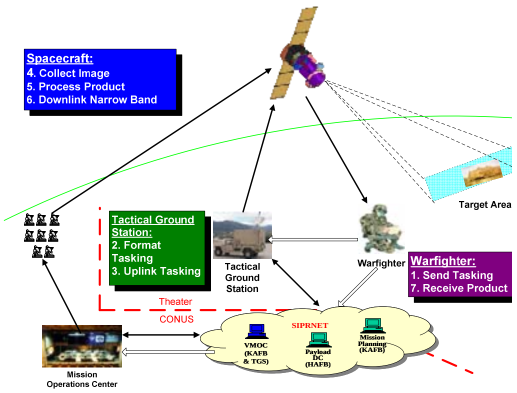

Figure 7. Tactical CONOPS

Upon receipt of the properly formatted tasking, TacSat-3 autonomously slews to the target, collects the data, processes the data, then downlinks the data directly to the warfighter. The tactical data product is determined by the original tasking, and is tailorable to meet the warfighter's needs and communications capabilities. TacSat-3's objective is to demonstrate in theater, the tasking, imaging, processing, and direct down link of the HSI data in less than 10 minutes. Once the tactical product has been disseminated in theater, the raw data is downlinked to the next available site. The raw data can be further processed for more detailed products.

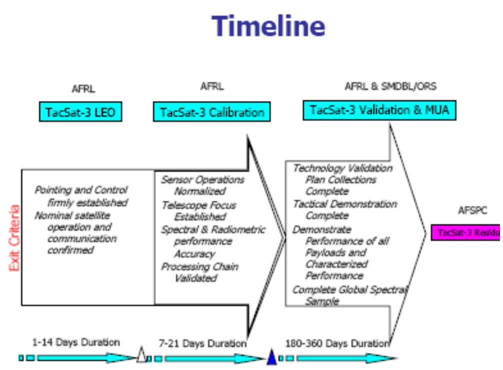

Figure 8. Mission Timeline

An important aspect of the TacSat-3 CONOPS will be the Military Utility Assessment (MUA). Military Utility is a quantitative expression of how well it meets its overall objectives. [8] Figure 8 shows the sequence of events to complete TacSat-3 science and technology goals. The TacSat-3 MUA is user oriented and will provide feedback for the mission design and provide quantitative information on the value HSI for decision making on future systems. A Joint MUA Integrated Product Team has been formed to complete the TacSat-3 analysis and is being led by the Operationally Responsive Space Office. The two components of MUA will be static experiments and participation in exercises. The sites have been identified for static experiments, target arrays have been designed and ground truth systems are already in place. Participation in field exercises is being planned but will be based on the actual launch date.

5.0 INTERNATIONAL PARTICIPATION

The United Kingdom, Canada, and Australia plan to participate in the TacSat-3 experiments to gain better understanding of the value of spaceborne HSI sensors. The Air Force International Affairs Office is coordinating collaboration which will be done under existing agreements. Specific activities are still in the planning stages, but potentially Australia DSTO will use the UHF tactical communications ground station similar to Army Ground Station and demonstrate tasking and direct downlink over ground sites in Australia. Canada will support the Australian experiments using tools developed under multiple airborne experiments. UK DSTL is looking at MOD ground sites for tasking with the end objective being to explore, and demonstrate the potential military applications of a small hyper-spectral satellite. The international collaboration will provide lessons learned about the practical problems of operating a small satellite that are potentially applicable to future systems.

6.0 SUMMARY

The TacSat-3 space experiment supports Operationally Responsive Space objectives and the HSI payload is expected to provide military utility directly to theatre commanders. TacSat-3 is a responsive space mission with a focus to provide a full capability direct to the warfighter, while meeting the cost and schedule portion of the responsive space paradigm. The CONOPS and JMUA development initiated with the ORS Office and other mission partners will enhance the ability to quickly exploit HSI data in the battlefield. Crucial to the success of the TacSat-3 mission are well defined mission objectives coupled with measurable and feasible mission

success criteria. Lessons learned from the TacSat-2 experiment have been reviewed and incorporated where appropriate. The TacSat-3 mission addresses needs for operational responsive space and has strong support from Air Force and DoD leadership. Significant challenges are still ahead – but TacSat-3 has a first class team to attack the issues!

REFERENCES

[1] Doggrell, L., *Operationally responsive space: a vision for the future of military space,* Air and Space Power Journal, Summer 2006

[2] Doyne, T., Hurley, M., and Davis, T., *Network-Enabled Program Management: Meeting the Space Acquisition Challenge*, High Frontier, Jan. 2006

[3] Bauer, T., Chakroborty, S., Conger, R., and Wertz, J., Systems Engineering for Responsive Space, Responsive Space Conference 2006, Los Angeles, CA, Apr. 24, 2006

[4] Pabich, P., *Hyperspectral Imagery: Warfighting Through a Different Set of Eyes*, Occasional Paper No. 31, Air War College, Maxwell AFB, AL, Oct. 2002

[5] Lockwood, R., Cooley, T., and Nadile, R., *Advanced Responsive Tactically-Effective Military Imaging Spectrometer (ARTEMIS) Design*, Proceedings of SPIE -- Volume 6661, Boston, MA, Sept. 12, 2007

[6] Davis, T. and Straight, S., *Development of the Tactical Satellite 3 for Responsive Space Missions*, AIAA Responsive Space Conference 2006, Los Angeles, CA, Apr. 25, 2006

[7] Galindez, R., and Davis, T., *Tactical Satellite 3 CDL Communications: A Communications Link for Mission Utility*, MILCOM 2007, Orlando, FL, Oct. 29, 2008

[8] Wertz, J., *ORS Mission Utility and Measures of Effectiveness*, AIAA Responsive Space Conference 2008, Los Angeles, CA, Apr. 29, 2008

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